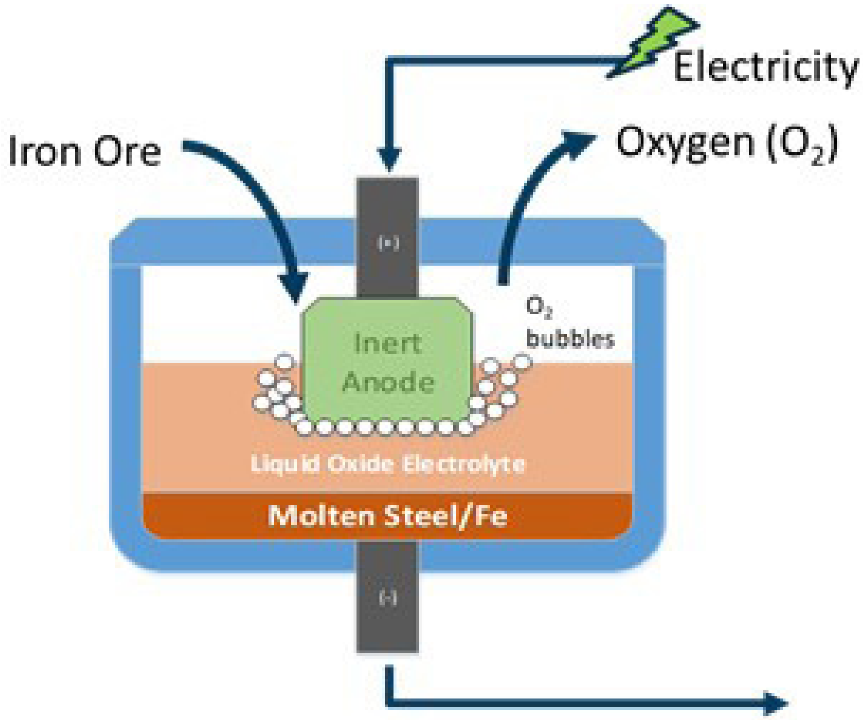
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Carbon-Free Iron for a Sustainable Future

Iron and steel manufacturing from both primary and secondary sources continues to be an essential enabler for a strong domestic economy. Primary iron production is dominated by integrated steel mills, which use a blast furnace to convert coke and iron ore into pig iron; the pig iron is then purified in a basic oxygen furnace (BOF) to make steel. In recent years, integrated producers have typically accounted for 35-40% of total domestic steel production. However, this integrated production process consumes a disproportionate share of energy – accounting for nearly two-thirds of total energy consumed in U.S. steel production and over 90% of total direct carbon dioxide emissions at these production facilities. Due to increasing strict emissions standards and cleanliness levels in high performance steel applications, alternative ironmaking processes have recently seen increased interest and production opportunities. These alternative ironmaking processes have the potential to significantly reduce energy, cost, and environmental impact.

This project is expected to advance molten oxide electrolysis (MOE), an emerging technology for primary iron and steel production. The MOE technology consists of an inert anode, a cathode, and an oxide electrolyte. The project will begin by acquiring operational knowledge and requirements for developing and operating an inert anode. This development will occur in a laboratory-scale furnace system, which will then test the inert anodes at different operating conditions (e.g., various temperatures, electrical currents, and geometry). The inert anodes will then be scaled up and incorporated into a pilot-scale MOE cell. The pilot-scale MOE cell will be optimized to accommodate the new inert anode designs. The pilot-scale inert anodes will then be tested for final MOE cell optimization, including week-long inert anode performance and endurance experiments.



Simplified cross-section schematic for the proposed molten oxide electrolysis cell. The liquid metal is produced at the cathode while oxygen gas is evolved on the anode.

Graphic image courtesy of Boston Metal.

Benefits for Our Industry and Our Nation

The MOE cell is expected to produce carbon free iron while potentially reducing energy usage, cost, and environmental impact. Using state-of-the-art MOE technology is anticipated to have a variety of benefits for iron and steel production compared to current U.S. iron production facilities, including:

- Energy savings of at least 20% at the iron production facility; though net impacts would depend on the source of electricity
- Reduction in net carbon dioxide emissions by about 20% when using grid electricity produced from natural gas, which increases to more than a 90% reduction using grid electricity produced from carbon-free sources including solar, nuclear, and wind
- Modular MOE design means that a potential all-electric steelmaking changeover could be gradual as incremental capacity is converted or added

Applications in Our Nation's Industry

The MOE technology will have a variety of benefits to iron and steel manufacturers. MOE can be applied to producing primary iron. MOE-produced iron can also be used as a scrap substitute to improve the quality of steel produced by electric arc furnaces (EAF). Other applications for MOE include ferrochromium production and specialty steels and alloys, such as low-carbon advanced high strength steels and electrical steels.

Project Description

The project objective is to mature the molten oxide electrolysis (MOE) technology for iron production. While lessons were learned from previous efforts, significant development is needed to successfully run an inert anode in a MOE self-heated cell at a production scale to produce carbon-free iron. The project outcomes address MOE cell design steps: (a) development and design of inert anodes with respect to operational requirements; (b) modification and optimization of the MOE cell design to accommodate anode operation; and (c) pilot-scale demonstration of carbon-free iron ingots. The pilot-scale MOE cells should benchmark the inert anodes' performance and functional behavior, and validate stable iron and oxygen production with an anode mass reduction of less than 5% over the course of the week-long experiment.

Barriers

- Successive refinement of the inert anodes' composition, geometry, and supporting systems is required, which indicates that the pilot-scale tests may require significant revisions to the MOE cells
- Full-scale MOE prototypes will need to successfully demonstrate improved anode performance, as well as reduced energy consumption and carbon emissions

Pathways

The project is structured to address key barriers and minimize risk. The ultimate goal is to produce MOE self-heated cells for primary iron and steel production that could be subsequently commercialized.

The first project pathway will validate the operational conditions for sub-scale inert anodes. This validation will involve rapid testing for these anodes in a small "lab cell" furnace system to determine the current, geometry, temperature, and alloy composition impacts on anode performance and longevity.

The second pathway will seek to apply the obtained knowledge from laboratory-scale anode tests to develop pilot-scale anodes. These anodes will be designed to be capable of operating in MOE self-heated cells (1000's of amps). These anodes will also be tested in the MOE cells when the new designs are procured.

The third pathway will determine the final optimization for the inert anodes with respect to endurance in the MOE cells. This will be accomplished via longer duration MOE cell experiments (~1 week each). The purpose for these experiments will be to study the inert anode life expectancy, as well as the iron production efficiency.

Milestones

This three-year project began in 2018.

- Develop detailed operational knowledge and requirements needed to pre-condition, start and run an inert anode (Completed)
- Derive, procure, and test new pilot-scale inert anode designs that meet the necessary MOE self-heated cell operational requirements (2020)
- Successfully operate and document stable oxygen and iron production with a pilot scale MOE cell (2021)

Technology Transition

Following successful project completion, Boston Metal intends to advance the technology towards commercialization rapidly. A commitment from a partner or consortium will be required to build a small-scale commercial demonstration plant, which is anticipated within one year after project completion. Construction of the first production plant using the MOE technology could be completed within three years after this project ends. It is likely Boston Metal would bundle high-value components, licensed IP, and technical support to customers who plan to build plants that produce iron. These customers include current users of low-carbon steels, iron and steel producers, and potentially mining firms looking to move up the value chain. Technical support provided will enable the MOE design to be scaled up or down as needed to meet customer requirements.

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